

Development of large area rf ion sources for fusion applications

S. B. Wells, Y. Takeiri, A. F. Newman, R. McAdams, and A. J. T. Holmes

Citation: *Rev. Sci. Instrum.* **63**, 2735 (1992); doi: 10.1063/1.1142839

View online: <http://dx.doi.org/10.1063/1.1142839>

View Table of Contents: <http://rsi.aip.org/resource/1/RSINAK/v63/i4>

Published by the [American Institute of Physics](#).

Related Articles

Production of negative ions on graphite surface in H₂/D₂ plasmas: Experiments and srin calculations
Phys. Plasmas **19**, 063503 (2012)

Electrical shielding box measurement of the negative hydrogen beam from Penning ion gauge ion source
Rev. Sci. Instrum. **83**, 063302 (2012)

Meniscus and beam halo formation in a tandem-type negative ion source with surface production
Appl. Phys. Lett. **100**, 233507 (2012)

Extracted current saturation in negative ion sources
J. Appl. Phys. **111**, 113303 (2012)

Source fabrication and lifetime for Li⁺ ion beams extracted from alumino-silicate sources
Rev. Sci. Instrum. **83**, 043303 (2012)

Additional information on *Rev. Sci. Instrum.*

Journal Homepage: <http://rsi.aip.org>

Journal Information: http://rsi.aip.org/about/about_the_journal

Top downloads: http://rsi.aip.org/features/most_downloaded

Information for Authors: <http://rsi.aip.org/authors>

ADVERTISEMENT



AIP Advances

Now Indexed in Thomson Reuters Databases

Explore AIP's open access journal:

- Rapid publication
- Article-level metrics
- Post-publication rating and commenting

Development of large area rf ion sources for fusion applications

S. B. Wells, Y. Takeiri,^{a)} A. F. Newman, R. McAdams, and A. J. T. Holmes
AEA Technology, Culham Laboratory, Abingdon, Oxon OX14 3DB, England

(Presented on 2 October 1991)

A rf ion source with a large extraction area suitable for fusion applications is considered. The source is a metallic magnetic multipole bucket with an internal antenna to couple the rf (at a frequency of 2 MHz) to the plasma. The source is diagnosed by an array of Langmuir probes to measure uniformity, density, and temperature and a small probe accelerator to extract a negative ion beam. A two-turn antenna is found to couple more power into the plasma than a half-turn antenna. When operated as a negative ion source at low powers, the source efficiency is found to be high and not to have a strong dependence on gas pressure. An extracted negative ion current density of about 4 mA/cm² at 7 mTorr was obtained when 3 kW of power was coupled into the plasma.

I. INTRODUCTION

There is interest in the development of rf ion sources of both positive and negative ions, especially for fusion applications. The rf sources have two main advantages over conventional filament-driven sources. First, they do not contain many filaments that limit the lifetime of the source by erosion and fatigue. Second, a higher current density of D⁺ can be achieved for a given power, hence showing greater efficiency. We have paid particular attention to the production of negative ions since they can be neutralized with greater efficiency than can positive ions at the high energies (>200 keV) required in future fusion applications.

Feist *et al.* at IPP Garching¹⁻³ have developed a positive ion source utilizing a quartz vessel with an external antenna and magnetic cusps for confinement on the back wall only. They report a hydrogen positive ion current density of ~750 mA/cm² with a proton yield of 90% at a rf power of ~140 kW. Our experimental setup is intended to improve the efficiency as we use an internal antenna and have additional magnetic cusps for confinement on the side walls. In addition, because our source is metallic, we do not require extra pumping around the source to prevent its implosion. However, protection of the antenna against rf arcing is a major technical difficulty presented by the internal antenna.

II. EXPERIMENTAL DETAILS

The ion source is a metal-walled multicusp bucket source of dimensions 550 mm × 310 mm × 210 mm deep.⁴ In our experiments the magnets were configured either in a simple checkerboard pattern, or in a supercusp pattern, which creates a magnetic tent filter to separate the driver and extraction regions. One small filament initiates the plasma. An internal antenna is used to couple the rf to the plasma. Two geometries of antenna have been investigated—first, a half-turn antenna, which consisted of two parallel rods inside the chamber that were joined into

a loop outside (strictly speaking, this is a single-turn antenna with only part of it immersed in the plasma), then a two-turn antenna contained completely within the chamber. Each antenna is water cooled and shielded from breakdown to the plasma by ceramic tubing (half-turn antenna) or a thin ceramic coating bound with fiberglass material (two-turn antenna). The source (configured as a negative ion source) is shown schematically in Fig. 1.

The rf power supply is a 50 kW, 2 MHz oscillator. The power is coupled into the antenna through a coaxial transformer.² A variable capacitor is connected in series with the antenna so that the circuit can be tuned for maximum power transfer. The rf tuning circuit is shown in Fig. 2. This diagram indicates the configuration of the so-called half-turn antenna.

The source plasma is diagnosed by an array of 16 Langmuir probes, ten along the long axis and six along the short axis. These measure the plasma uniformity, and allow estimation of plasma density and electron temperature throughout the source. Measurements were taken over the range of gas pressures 3–11 mTorr. The working gas was deuterium.

A small probe diode 10 kV accelerator (with an extraction aperture of 1.5 mm diam) at the extraction plane can be used to extract either negative or positive ions.⁴ Permanent magnets in the second (extraction) electrode constitute an electron trap to prevent electrons reaching the Faraday cup in the case of negative ion extraction.

The rf power fed to the antenna is estimated from measurements of the voltage drop across the antenna using two high voltage rf probes, and the current in the antenna loop using a current transformer, taking the phase difference into account. At present there is a large error in the estimation due to difficulties in measuring the relative phases between the voltage and current signals from oscilloscope traces.

III. EXPERIMENTAL RESULTS

The result of plasma diagnosis and negative ion extraction are compared for three different source conditions. All

^{a)}Permanent address: National Institute for Fusion Science; Nagoya 464-01, Japan.

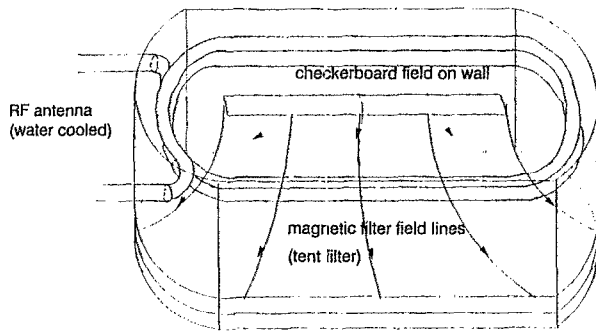


FIG. 1. The rf negative ion source (with two-turn antenna and supercusp magnet configuration).

results were measured at 7 mTorr, unless stated otherwise, and constant rf power.

A. Comparison of results obtained using the half-turn and the two-turn antennas, both with a checkerboard magnet configuration

1. Tuning characteristics

The positive current density measured by Langmuir probe 6 (positioned 66 mm from the center of the source) as the tuning capacitance is varied shows the tuning characteristics of the two antennas. In each case the resonance has a similar half-width (about 150 pF). However, the tuning capacitance is reduced from about 1050 pF for the half-turn antenna to about 910 pF for the two-turn antenna due to its increased inductance.

2. Power consumption

The power consumed by the plasma is assumed to be the difference between the powers fed to the antenna with and without the plasma load. In each case the rf circuit is tuned to resonance. For the half-turn antenna, the peak power consumed by the plasma is approximately $5-3.5 = 1.5$ kW. For the two-turn antenna, the peak power is increased to approximately $8 - 5 = 3$ kW.

3. Electron temperature and plasma density

For both antennas (both with checkerboard magnet configuration) the electron temperature lies approximately in the range 3–5 eV. The temperature increases slightly with depth. Typical results are plotted in Fig. 3.

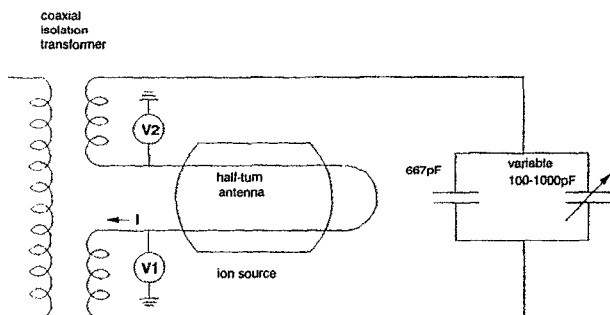


FIG. 2. The rf tuning circuit.

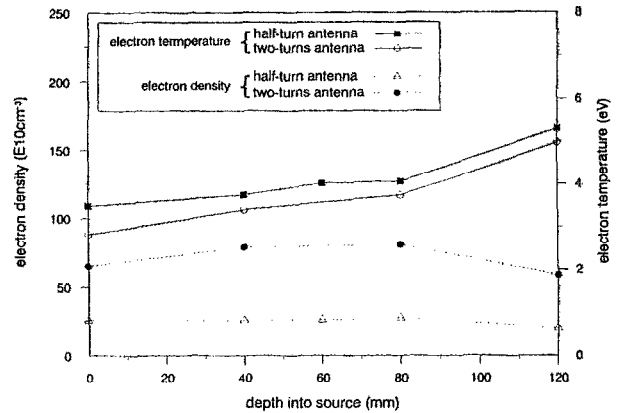


FIG. 3. Comparison of electron density and electron temperature against source depth for half- and two-turn antennas (checkerboard magnet configuration).

For the half-turn antenna, both the electron density and the positive ion density are estimated to be in the range $2-3 \times 10^{11} \text{ cm}^{-3}$. When the antenna is changed to the two-turn antenna (still with the checkerboard magnet configuration), the electron density is increased to $5-7 \times 10^{11} \text{ cm}^{-3}$, and the positive ion density (which is estimated with less accuracy) is increased to $5-10 \times 10^{11} \text{ cm}^{-3}$. This is indicative of greater rf coupling. Figure 3 compares the electron density as a function of depth for the two antennas. In each case, the densities are fairly uniform with depth into the source, as expected for a source with no magnetic filter.

4. Uniformity

An indication of the uniformity is given by measurements of the positive current density at each of the 16 Langmuir probes. Figure 4 shows that the uniformity is very good for the case of the half-turn antenna but is less good with the two-turn antenna. In this case the probes along the long axis on the left-hand side of the source indicate a slightly higher plasma density than those on the right-hand side. It is thought that this could be due to increased rf coupling since the ends of the antenna overlap at the left-hand end to give three passes of the antenna instead of two, as elsewhere.

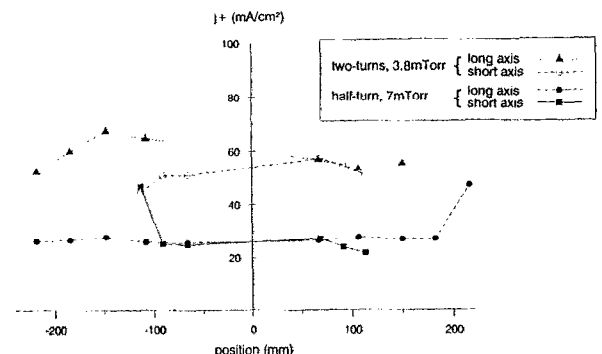


FIG. 4. Source uniformity using the half- and two-turn antennas (checkerboard magnet configuration).

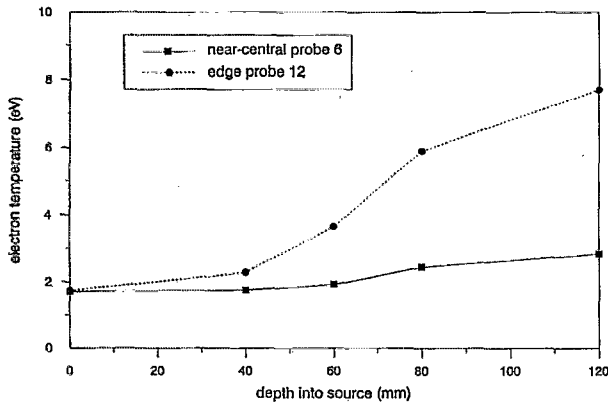


FIG. 5. Comparison of electron temperature depth profiles for an edge probe and a near-central probe for the negative ion source.

B. Results obtained under operation as a negative ion source (two-turn antenna with supercusp magnet configuration)

1. Tuning characteristics and power consumption

Neither of these is affected by simply changing the magnet configuration from checkerboard to supercusp.

2. Electron temperature and plasma density

When the source is operated as a negative ion source, with a supercusp magnet configuration and using the two-turn antenna (for enhanced power coupling), the electron temperature is reduced to 1.5–2 eV across the whole of the extraction plane. This is expected due to greater confinement of the electrons in the driver region behind the tent filter. Along the central axis, the electron temperature gradually increases with source depth to 3 eV. However, we measured high electron temperatures (5–12 eV) in the driver region. A comparison of the variation of electron temperatures with depth for the near-central probe 6 (which is always in the extraction region) and the edge probe 12 (which protrudes into the driver region for depth > 60 mm) is given in Fig. 5.

The plasma density is less uniform with depth under the condition of the supercusp magnet configuration than that of the checkerboard configuration. On the central axis of the source, close to the extraction plane, both electron and positive ion densities are estimated to be $5 \times 10^{11} \text{ cm}^{-3}$ (as for the two-turn antenna, checkerboard setup). Deeper into the source (> 80 mm, but still in the extraction region), the positive ion density remains at this value, but the electron density falls off by about on-half. Estimates of the electron density may be in error if the measuring probe protrudes into the magnetic field of the tent filter. However, this may imply that the negative ion density increases with source depth.

3. Extracted negative ion current density

The extracted D^- negative ion current density is observed to increase with depth. The negative current density varies little with gas pressure (see Fig. 6), unlike conventional filament-driven sources, where a noticeable reduc-

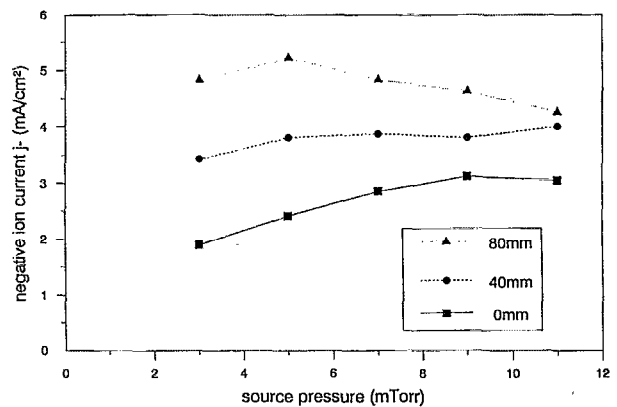


FIG. 6. Comparison of the variation of the negative ion current with source pressure for three source depths.

tion occurs. This indicates the potential (at least at low operating powers) for the rf source to operate at low gas pressures.

Although the extracted current density is low, the source efficiency is good. We extracted about 4 mA/cm^2 at 7 mTorr and 40 mm depth when the power coupled into the plasma was about 3 kW. Typical figures for a conventional filament-driven source are 16 mA/cm^2 at 12 mTorr for 48 kW.⁴

4. Uniformity

The source uniformity is poor. The difference between plasma densities along the long axis of the source is accentuated, and along the short axis the plasma density falls off very rapidly with distance from the center.

IV. DISCUSSION AND FURTHER WORK

In order to increase the extracted current density, the coupling between the rf generator and the plasma needs to be improved. At present, at most 10 kW has been dissipated in the antenna, though the generator is capable of providing 50 kW. Coupling (and consequently the plasma density) is greater when using the two-turn antenna than when using the half-turn antenna. It is expected that a four- or five-turn antenna should further improve the coupling due to its increased inductance.

At low operating powers we have demonstrated a high source efficiency. This rf source has the potential to form the basis of an efficient and reliable positive (with the checkerboard magnet configuration) or negative (with the supercusp configuration) ion source, which can operate at low gas pressures.

¹J. H. Feist, Minutes of the European Neutral Injection Joint Development Committee JDC 1/89.

²W. Krauss, R. Bilau-faust, J. H. Feist, E. Speth, 16th Symposium on Fusion Technology, London, United Kingdom, 1990.

³H. Feist, W. Krauss, and E. Speth, Minutes of the European Neutral Injection Joint Development Committee JDC 1/90.

⁴A. J. T. Holmes, L. M. Lea, A. F. Newman, and M. P. S. Nightingale, *Rev. Sci. Instrum.* **58**, 223 (1987).